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Space systems — Stress-corrision cracking — Part 2: Selection of metallic materials

Systèmes spatiaux — TBD — Partie 2: TBD

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

ISO 16455-2 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

ISO 16455 consists of the following parts, under the general title *Space systems — Stress-corrision cracking*:

— *Part 1: Test methods for determining susceptibility of metals*

— *Part 2: Selection of metallic materials*

Introduction

The ratings in this International Standard apply only to exposures in sodium chloride environments. Most of the data was obtained in laboratories where the alloys were tested in alternate immersion according to ISO 11130:1999. Alloys used for electrical wiring and other similar non-structural electrical or electronic applications are exempt from the requirements of this International Standard.

This document is intended to provide guidance for the selection of metallic materials for stress-corrosion resistance in a sodium chloride environment. It is based on NASA Marshall Space Flight Center (MSFC) standard MSFC-STD-3029, Multiprogram/Project Common-Use Document Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments, Materials, Processes, and Manufacturing Department Metallic Materials and Processes Group, and on ISO documents previously published under TC 156. Some ratings presented in the European Cooperation for Space Standardization (ECSS) standard ECSS-Q-70-36A, Material Selection for Controlling Stress Corrosion Cracking (superseding ESA-PSS-01-736-1), were also included.

Space systems — Stress-corrision cracking — Part 2: Selection of metallic materials

1 Scope

This International Standard defines the design criteria that shall be used for the selection of metallic materials in order to prevent failure due to stress-corrosion cracking (SCC). It classifies alloys for stress-corrosion susceptibility in sodium chloride (NaCl) environments and describes the method to seek materials approval from the stress-corrosion standpoint. It does not discuss other forms of environmental cracking, such as corrosion fatigue or hydrogen embrittlement.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

MSFC-STD-3029, Multiprogram/Project Common-Use Document Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments, Materials, Processes, and Manufacturing Department Metallic Materials and Processes Group, May 22, 2000ISO 7539-1:1987, *Corrosion of metals and alloys – Stress corrosion testing — Part 1: General guidance on testing procedures*

ISO 7539-2:1989, *Corrosion of metals and alloys – Stress corrosion testing — Part 2: Preparation and use of bent-beam specimens*

ISO 7539-3:1989, *Corrosion of metals and alloys – Stress corrosion testing — Part 3: Preparation and use of U-bend specimens*

ISO 7539-4:1989, *Corrosion of metals and alloys – Stress corrosion testing — Part 4: Preparation and use of uniaxially loaded tension specimens*

ISO 7539-5:1989, *Corrosion of metals and alloys – Stress corrosion testing — Part 5: Preparation and use of C-ring specimens*

ISO 7539-6:1989, *Corrosion of metals and alloys – Stress corrosion testing — Part 6: Preparation and use of pre-cracked specimens for tests under constant load or constant displacement*

ISO 7539-7:1989, *Corrosion of metals and alloys – Stress corrosion testing — Part 7: Slow strain rate testing*

ISO 7539-8:2000, *Corrosion of metals and alloys – Stress corrosion testing — Part 8: Preparation and use of specimens to evaluate weldments*

ISO 7539-9:2003, *Corrosion of metals and alloys – Stress corrosion testing — Part 9: Preparation and use of pre-cracked specimens for tests under rising load or rising displacement*

ISO 8044:1999, *Corrosion of metals and alloys – Basic terms and definitions*

ISO 8407:1991, *Corrosion of metals and alloys – Removal of corrosion products from corrosion test specimens*

ISO 9227:1999, *Corrosion tests in artificial atmospheres – Salt spray tests*

ISO 11130:1999, *Corrosion of metals and alloys – Alternate immersion tests in salt solution*

ISO 16455-1, *Space systems – Stress corrosion cracking – Part 1: Test methods for determining susceptibility of metals*

NOTE In case of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. The content of this document, however, does not supersede applicable laws and regulations unless a specific exemption has been obtained.

3 Terms, definitions, symbols, units, and abbreviated terms

For the purposes of this document, the following term applies.

3.1
stress corrosion
the synergistic attack on a metal caused by the simultaneous action of a corrosive environment and nominally static tensile stress (residual or applied), which usually results in the formation of cracks. This process frequently results in a significant reduction of the load-bearing properties of metallic structures

3.2
Symbols and abbreviated terms

ASTM	American Society for Testing and Materials
AT	annealed and precipitation hardened
°C	degree Celsius
CDA	Copper Development Association
CH900	cold-worked and aged at 482 °C (900 °F)
cm	centimetre
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
°F	degree Fahrenheit
H1000	hardened at 538 °C (1 000 °F)
HT	work-hardened and precipitation-hardened
IEC	International Electrotechnical Commission
ISO	International Standardization Organization
ksi	kilopound per square inch
MIL-HDBK	military handbook
MPa	megapascal
MSFC	Marshall Space Flight Center
MUA	Materials Usage Agreement

NaCl sodium chloride

NASA National Aeronautics and Space Administration

SCC stress-corrosion cracking

SCT subzero cooling and tempering

SRH950 Solution treated and tempered at 510 °C (950 °F).

STD standard

UNS Unified Numbering System

UTS ultimate tensile strength

4 General information

4.1 Background

The combined action of sustained tensile stress and corrosion may cause premature failure of a susceptible material. Corrosion or static tensile stress alone will not initiate such cracks. This cracking has not been observed for metal surfaces in compression. Virtually all metal systems contain one or more alloys that are susceptible to stress-corrosion cracking in some environments. Certain metallic materials are more susceptible than others, and stress corrosion cracking occurs in both brittle and ductile materials. If a susceptible material is placed in service in a corrosive envi ronment under tension of sufficient magnitude and the duration of service is sufficient to permit the initiation and growth of cracks, failures will occur at a stress lower than the material would normally be expected to withstand. The corrosive environment need not be severe in terms of general corrosive attack. Service failures due to stress corrosion are frequently encountered for which the surfaces of the failed parts are not visibly corroded in a general sense. If failure of a susceptible material in a corrosive environment is to be avoided, the total tensile stress (residual and applied) in service shall be maintained at a safe level.

4.2 Principal variables that influence stress corrosion

The principal variables that significantly interact to influence stress-corrosion cracking are alloy composition and related metallurgical factors; sustained surface tensile stress, either residual, assembly, or applied; and environment, including temperature and time. Certain alloys and heat treatments in a given metal system are more resistant to stress-corrosion cracking than others.

4.3 Effect of grain orientation on stress-corrosion susceptibility

4.3.1 Processing operations

Rolling, extruding, and forging are the most common processing operations employed in the production of standard wrought forms of metal. All produce a flow of metal in a predominant direction so that, microscopically, the metal is no longer isotropic. As a result, the properties of the metal vary according to the direction in which they are measured. The extent of directional variation depends on the property of interest. For susceptibility to stress-corrosion cracking, the directional variation can be appreciable and must be considered in the design of fabricated hardware.

4.3.1.1 Rolling and extruding

The anisotropy of grain orientation produced by rolling and extruding is illustrated schematically in Figure 1. Taking the rolled plate as an example, it is conventional to describe grain orientation in three directions. The direction of rolling is the longitudinal direction, the direction perpendicular to the longitudinal and in the plane of the plate is the long transverse direction, and the direction through the thickness of the plate is the short transverse direction. For certain shapes, the simple rules may not apply and grain orientation can only be established by experience with the shape and knowledge of the forming methods. As an example, consider the thick tee section illustrated in Figure 2.

4.3.1.2 Forgings

Identifying the short transverse direction of forgings also requires consideration. In a forging operation, the flow of metal is influenced and constrained by the shape of the die cavity. For complex shapes, there may be several regions where a short transverse direction exists. The direction perpendicular to the parting plane of the dies is always short transverse as illustrated in Figure 3.

4.3.2 Short transverse direction

The stress-corrosion resistance of metals, especially aluminum alloys, is lower in the long transverse direction than it is in the longitudinal direction; however, it is worse in the short transverse direction. Figures 2 and 3 illustrate undesirable situations in which tensile stresses due to assembly have been applied in the short transverse direction. Similar situations must be avoided for optimum resistance to stress-corrosion cracking.

4.4 Stress considerations

In designing for stress-corrosion resistance it is important to realize that stresses are additive, and threshold stresses for susceptibility are often low. All possible sources of stress must be considered to ensure that the threshold stresses are not exceeded. Stresses resulting from operational, transportation, and storage loads are often anticipated during design. Assembly and residual stresses may not be anticipated and in many cases have been the major contributors to stress-corrosion failure. There have been stress-corrosion failures where the design stresses were intermittent and of short duration and were a minor contributor to failure.

4.4.1 Examples of assembly stresses

Assembly stresses can result from improper tolerances during fit-up (Figures 2 and 3), overtorquing, press fits, high interference fasteners, and welding.

4.4.2 Examples of residual stresses

Residual stresses can result from welding, machining, forming, and heat-treating operations. Figure 4 illustrates the distribution and relative magnitudes of stress resulting from conventional heat treating and forming operations.

4.5 Susceptibility of engineering alloys

4.5.1 Aluminum alloys

Many aluminum alloys exhibit excellent resistance to stress-corrosion cracking in all standard tempers. However, the high-strength aluminum alloys, which are of primary interest in aerospace applications, must be approached cautiously. Some of these alloys are resistant only in the longitudinal grain direction, and the resistance of others varies with the specific temper. Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals.

4.5.1.1 Mechanical stress relief

Conventional processing methods designed to optimize strength, such as rolling, forging, casting, and welding, can result in high residual stresses. These high residual stresses are usually greater in aluminum products than in wrought forms of other metals, especially in thick sections. It is for this reason that wrought, heat-treatable aluminum alloys shall be mechanically stress relieved (the TX5X or TX5XX temper designations) whenever possible. If the alloy is resolutioned, residual stresses may be reintroduced rendering it more susceptible to stress-corrosion cracking again.

4.5.1.2 Machining wrought aluminum

Both the residual stress distribution and the grain orientation must be carefully considered in designing a part to be machined from wrought aluminum. Machining will alter the stress distribution, and it may also result in the exposure of a short transverse region on the surface of the finished part that will be subject to tension in service. Examples of exposure of a short transverse region on machined parts are illustrated in Figures 2 and 3.

4.5.2 Ferrous alloys

Carbon and low-alloy steels with ultimate tensile strengths below 1 241 megapascal (MPa) (180 kilopounds per square inch [ksi]) are generally resistant to stress-corrosion cracking. Austenitic stainless steels of the 300 series are also generally resistant but not immune. The free machining grades (e.g. 303 and 303SE) appear to be less resistant to SCC than other steels of this type. The susceptibility of the martensitic stainless steels of the 400 series depends on composition and heat treatment. Precipitation-hardening stainless steels vary in susceptibility from extremely high to extremely low depending on composition and heat treatment. The susceptibility of precipitation-hardening stainless steels increases with decreasing heat treatment tempering temperatures. Ferritic and duplex stainless steels are not as resistant to stress corrosion cracking as are austenitic stainless steels.

4.5.3 Nickel alloys

As a class, alloys with high nickel content are resistant to stress-corrosion cracking.

4.5.4 Copper alloys

Atmospheres containing pollutants of sulfur dioxide, oxides of nitrogen, and ammonia are reported to cause stress corrosion cracking of some copper alloys. Chlorides present in marine atmospheres may also cause stress corrosion cracking but to a lesser extent than the previously listed pollutants. Many copper alloys containing more than 20-percent zinc are susceptible to stress corrosion cracking, even in the presence of alloying additions that normally impart resistance to stress corrosion.

4.5.5 Titanium alloys

Many titanium alloys are resistant to stress-corrosion cracking in NaCl environments. However, alloys such as Ti-2,5% Cu, and in particular components with flaws, may become susceptible. It has been reported that some titanium alloys may appear immune to stress-corrosion cracking in an NaCl environment when using smooth specimens; however, they may crack once a flaw has been introduced. It appears that some of these alloys do not easily develop a surface alteration (e.g. a pit) for the initiation and propagation of stress-corrosion cracking when they are exposed to NaCl environments.

4.5.6 Magnesium alloys

The susceptibility to stress corrosion of the magnesium alloys presented in this International Standard ranges from high to low, depending on the particular alloy. For some magnesium alloys (e.g. AZ31B, AZ61A, and AZ80A) stress relief is required to prevent stress-corrosion cracking.

5 Limitations

5.1 Temperature and environment limitations

The stress-corrosion susceptibility of the alloys included in this International Standard was determined at ambient temperature by conducting stress-corrosion tests or by service experience with fabricated hardware.

The majority of the stress-corrosion tests was performed by exposing specimens to either 3,5-percent alternate immersion or 5-percent salt spray (with alternate immersion being the preferred method). In many occasions, parallel tests were performed in a seacoast environment or in a high humidity cabinet. Some data generated with the slow strain rate technique also involved the use of an NaCl solution as the corroding agent. Use of the criteria established herein shall be limited to designs for service involving similar exposure conditions. Behaviour of the listed metallic materials at elevated temperature and/or in specific chemical environments other than those previously mentioned must be ascertained by additional testing.

5.2 Weldments

Weldments present a special problem in designing for resistance to SCC. In addition to the susceptibility of the parent metals, it is also necessary to consider the filler metal and the microstructural effects of heat and deformation introduced by the welding operations and subsequent thermal treatments. Tensile properties shall be determined on a gauge length that shall include the weld, the heat-affected zone, and parent material adjacent to the heat-affected zone. Hardness tests shall be used to identify these areas. Susceptibility data are not as extensive for weldments as for alloys in mill form because of the additional variables that must be considered. Most of the design criteria for weldments in this International Standard are limited to aluminum alloys, selected stainless steels in the 300 series, and other specific alloys listed in Tables I through 5.

5.3 Specific test data

The majority of the alloys presented in this International Standard were evaluated by NASA or the European Space Agency (ESA) to support space programs. No specific data are included in this International Standard because of the large amount of space that would take.

5.4 Data limitations

This International Standard does not purport to be all inclusive of factors and criteria necessary for the total control of stress-corrosion cracking in alloys. Data on stress-corrosion susceptibility may be insufficient for many applications involving unfamiliar materials or unusual combinations of materials and environments. To ensure adequate stress-corrosion resistance in these situations, it will be necessary to conduct a detailed evaluation of susceptibility. Testing may also be necessary in those cases.

5.5 Defect-free surface limitation

This International Standard is based on data obtained using smooth specimens. No initial flaws were introduced. The presence of a stress concentration in the form of a notch or flaw can be a prerequisite for stress-corrosion to occur. Some materials, for example, certain types of titanium alloys, may appear immune to stress-corrosion in laboratory tests using smooth specimens but can develop severe cracking in the same environment once a flaw has been introduced.

6 Testing of materials for stress-corrosion susceptibility

The testing and rating of materials for stress-corrosion susceptibility are discussed in ISO 16455-1. Therefore, this topic will be discussed only in general in this clause. The 3,5-percent salt alternate immersion under constant strain and alternate immersion under constant load are the most common methods to evaluate materials for stress-corrosion susceptibility. Among the two stressing methods, the constant strain method is considered the primary method in this document. Whenever possible, round specimens with a 0.318-cm (0.125-in) diameter in the gauge length and fabricated in the short transverse direction shall be used. However, other specimen configurations exist (flat tensile, C-rings, bent-beams, etc.). The following documentation must be provided when submitting data for the classification of materials in this International Standard: chemistry, hardness, mechanical properties, UNS designation, manufacturer, lot number, applicable specification, product form, thickness or diameter, process history, temper designation or heat treatment steps, test environment, type and dimensions of the specimens, applied stress, stress direction in relation to grain orientation, number of failures, number of replicates, days to failure, test duration, reduction in load carrying ability, etc. If applicable, welding method or surface treatments applied shall be reported.

Additional complementary information such as tables, illustrations (e.g. optical pictures, photomicrographs), or annexes can be added as desired. Any deviations from standard procedures shall be reported.

7 Rating of alloys for stress-corrosion susceptibility

The alloys listed in this International Standard were classified in three classes in Tables 1 through 12 according to their relative susceptibility to stress-corrosion cracking. A table that combines these 12 tables in one is also included (Table 13). Many materials in this International Standard have ratings that vary with material condition. These ratings can be viewed in consecutive rows in Table 13, which is very useful for the designer. The ratings presented in this International Standard are based on testing and experience and apply only to the environments described in this clause (NaCl environments). In the case of borderline alloys between two classifications, a conservative approach shall be followed. An alloy can be reclassified if a consensus is reached by stress corrosion experts based on additional data obtained or further analysis. If the form of the material (plate, bar, etc.) is not indicated in the tables, the rating applies to all forms of the material. The susceptibility to stresscorrosion for aluminum alloys varies with the grain orientation. The ratings presented in this International Standard are based on the worst-case stressing direction (e.g. the short transverse direction in the case of plate). For information on the classification criteria see ISO 16455-1.

8 Use of stress-corrosion ratings in design to prevent failures

Stress-corrosion cracking can be reduced through the use of one or more of the following techniques:

a) reduction of stress;

b) modification of the environment;

c) preventive methods (e.g., undamaged paint films);

d) selection of the most resistant alloy for the expected environment as described in the following subclause.

The ratings presented in this International Standard shall serve as a guide to designers for the selection of metallic materials for stress-corrosion resistance. Stress-corrosion failures occur suddenly with no warning signs, and the results have been catastrophic. In order to avoid these failures, the designers shall select alloys and tempers with the highest possible stress-corrosion ratings that still are suitable for the intended application. However, within a class and because of the relationship between strength and susceptibility to stress-corrosion cracking, it shall be a standard recommended practice to use the lowest strength material compatible with the design. The environment to which the structure will be exposed (including assembly, transportation, storing, and in-service environments) and the sustained tensile stresses derived from all sources (residual, assembly, and design stresses) shall be considered when making the material selection.

9 Materials selection criteria

This clause is provided to emphasize the importance of materials selection to avoid failures due to stress corrosion. The requirements for class 1, class 2, and class 3 materials are defined in ISO 16455-1.

9.1 Class 1 alloys (Tables 1 through 5)

Alloys, tempers, and weldments, which by testing and experience have shown high resistance to stress-corrosion cracking (class 1 [Tables 1 through 5]), shall be used preferentially, and approval is not required prior to use. All other alloys and weldments not listed as class 1, except as specifically exempted, shall be approved prior to use, assembly, or integration. This requirement is very important as stated, but it becomes even more important when it is prohibited to inspect or remove the part after it is assembled or integrated in a system. The procedure that shall be followed to request approval is described in clause 10. When material approval is required, that task shall be carried out by the responsible materials and processes organization.

9.2 Class 2 alloys (Tables 6, 7, and 8)

Alloys, tempers, and weldments that are moderately resistant to stress corrosion (class 2 [Tables 6, 7, and 8]) shall be considered for use only for cases where a suitable alloy with high resistance to stress-corrosion cracking (class 1) cannot be found. Approval is required before using class 2 alloys or weldments.

9.2.1 High installation stresses

Proposed utilization of class 2 materials in applications involving high-installation stress, such as springs or fasteners, shall not be approved.

9.2.2 Aluminum alloy sheet material

Sheet material (less than 0,64-centimetre [cm] (0.25-in) thick) of the aluminum alloys and conditions listed as class 2 in Tables 6, 7, and 8 is considered resistant to stress corrosion and does not require approval.

9.3 Class 3 alloys (Tables 9 through 12)

Alloys and tempers that are highly susceptible to stress-corrosion cracking (class 3 [Tables 9 through 12]) shall be considered for use only in applications where it can be demonstrated conclusively that the probability of stress corrosion is remote. The sustained tensile stress in critical grain directions, whatever its origin, is required to be significantly lower than the stress-corrosion threshold of the metal. Significantly lower is defined here as not more than 50-percent of the SCC threshold (which is not the same thing as 50 % of the yield strength), as obtained by using the primary SCC testing procedure described in ISO 16455-1 (by using the constant strain method, 0.318-in (0.125-in) diameter round specimens, 3,5 % NaCl alternate immersion per ISO 11130, and a minimum 30-day exposure), or by any of the alternate procedures described in the same document, if the mainline procedure cannot be applied. Since the SCC threshold obtained may be related to specimen type and size, specimen loading procedure, corrosiveness of the test environment, and length of exposure, it is very important to follow this mainline procedure in ISO 16455-1, whenever it is feasible. The use of class 3 alloys shall be avoided if the part is under sustained tensile stress in a corrosive environment and the SCC threshold is unknown. The SCC threshold for some hardened steels can be as low as 172 MPa (25 ksi) or less (e.g. hardened bearing steels), and for some aluminium alloys SCC thresholds as low as 41 MPa (6 ksi) have been reported (e.g. Al 2024-T3 and -T4) when stressed in the short transverse direction. Therefore, the safety concerns associated with the use of class 3 alloys under conditions that may promote SCC shall be considered very carefully, especially in situations where a failure would cause loss of life, injury, loss of property, or damage to the environment. For class 3 alloys, suitable protective measures shall be used, and the environment shall not promote corrosion. Hardware fabricated from these materials shall be inspected regularly for corrosion, and the potential for a stress-corrosion failure shall be assessed at that time. The use of class 3 materials requires approval prior to use, assembly, or integration. The rationale for the use of these materials shall be based on a detailed analysis of the potential for failure (see 10.1 and 10.2).

10 Request for materials approval prior to use, assembly, or integration

Fabrication of structures first and requesting material approval later is not an acceptable practice, especially if stress corrosion was not considered a design factor. Class 2 and class 3 alloys (Tables 6 through 12) in such structures require approval before the structure is put in service. If the material is rejected because of safety reasons or relatively high risk for a stress-corrosion failure, corrective action shall be taken.

10.1 Assessment of the potential for a stress-corrosion failure

A complete assessment of the stress-corrosion susceptibility as a potential for failure for the proposed or current use of class 2 and class 3 materials shall be submitted to the appropriate agency. The following information shall be submitted for each application being evaluated:

a) Part number;

b) Part name;

c) Next assembly number;

d) Manufacturer's name, address, and phone number;

e) Material – The material shall be identified as specified on the drawing. Provide specific alloy and temper designation of raw material from which the part is to be fabricated;

f) Heat treatment – List all thermal treatments that the part receives;

g) Size and form – List the approximate dimensions of the raw material from which the part is to be fabricated. Include the raw material form (bar, plate, sheet, extrusion, forgings, etc.);

h) Sustained tensile stresses – Estimate all the sustained tensile stresses. Include the magnitude and the direction with respect to grain orientation. List the stresses according to their source (i.e. process residual, assembly, design), and provide the basis on which the estimation was made. Note any special precautions to control stresses;

i) Special processing – Note any processes used for reducing tensile stresses (such as shot peening or stress relief treatments);

j) Weldments – Provide a stress-corrosion evaluation of all weldments and submit all information that may assist in that evaluation. For each weldment, list the alloy, form, and temper of the parent metal, filler alloy (if any), welding process, whether the weld bead was removed, and postweld thermal treatment or stress relief;

k) Environment – An evaluation shall be made as to the expected corrosive environment to which the part will be exposed during its lifetime. This includes exposure during fabrication, assembly, and component storage as well as environmental conditions during use. Include length of exposure, temperature, pressure, and concentration;

l) Protective finish – List any finishes that are applied for corrosion protection or which might affect the basic corrosion resistance of the component;

m) Function of part – Provide the basic function of the part (or if more pertinent the assembly);

n) Effect of failure – Provide the possible effect that failure of the part (or assembly) will have on all functions or missions of the major assembly involved. Indicate whether the part or assembly is a fracture-critical component (a part or assembly whose failure can lead to personal injury, loss of life, loss of a flight vehicle, hardware, or ground structures, loss of property, etc.);

o) Evaluation of stress-corrosion susceptibility – Include the rationale on which the material selection was made and an explanation as to why no stress-corrosion problems are expected;

p) Remarks – Include any additional information or explanatory notes not otherwise listed.

10.2 The materials usage agreement (MUA)

The MUA is the means for requesting approval of a material if required. It consists of gathering information necessary to determine the acceptability of the material for stress-corrosion resistance for the particular application. It serves as a method to promote the selection of stress-corrosion resistant alloys. Similar usages of the same or similar alloys can be submitted on a single MUA. The MUA requires approval by the responsible materials and processes organization. The MUA consists of, but is not limited to, the following information:

a) Project;

b) System;

c) Subsystem;

d) Originator;

e) Originator's organization, address, and phone number;

f) Identification of part;

g) Drawings and next assembly drawings;

h) Item description;

i) Material designation;

j) Manufacturer;

k) Specification;

l) Proposed effectivity/serial number;

m) Material description – thickness, weight, and exposed area;

n) Location on spacecraft – habitable or nonhabitable;

o) Fracture critical component – yes or no;

p) Environment – include pressure, temperature, and duration of exposure;

q) Application;

r) Rationale. This rationale is to include the information listed in 10.1.

10.3 Unlisted materials

The stress-corrosion resistance of alloys and weldments not listed in this International Standard shall be ascertained by tests conducted in an environment representative of the proposed application or by a direct comparison with similar alloys and weldments for which susceptibility is known. An MUA and a stress-corrosion evaluation, or the equivalent, shall be submitted to the appropriate agency before the proposed alloy is used.

10.3.1 Assessment of the susceptibility of unlisted materials by similarity

In some instances, the susceptibility to stress-corrosion cracking of materials not listed in this International Standard can be ascertained by a direct comparison with similar alloys and weldments for which susceptibility is known. Rating presented in this International Standard are for materials for which there is specific data obtained in an NaCl environment available for review. If the proposed material is not rated in this International Standard but a rating can be obtained by similarity, that rating shall be included and indicate that it was obtained by similarity. Materials properties to compare in such cases shall include chemistry, process history, product form, heat treatment condition, hardness, mechanical properties (especially the ultimate tensile strength), etc.

10.3.2 Assessment of the susceptibility of unlisted materials by testing

If the susceptibility to stress-corrosion cracking of an unlisted material that is going to be under sustained tensile stresses in a non-benign environment cannot be ascertained by similarity, then it shall be determined by testing in an environment representative of the proposed application.

10.4 Protective coatings and lubricants

Protective coatings do not change the stress-corrosion rating of alloys to which they are applied. Though there are coatings that may delay the onset of stress-corrosion, they may contain imperfections or their integrity may be degraded in service. Class 2 and class 3 alloys thus treated must be identified, and a request for approval prior to their use, assembly, or integration shall be submitted to the appropriate agency through the MUA and stress-corrosion evaluation method or the equivalent process.

10.5 Surface treatments

Surface treatments, such as carburizing or nitriding, which locally modify the compositional or thermal treatment, may adversely affect the stress-corrosion rating of materials to which they are applied. All materials thus treated must be identified and an MUA and stress-corrosion evaluation forms, or the equivalent, shall be submitted for approval prior to their use.

11 Notes

11.1 Intended use

This International Standard is intended to establish design requirements for the selection of metals used to fabricate space hardware and ground support equipment so that stress-corrosion failures are prevented.

11.2 Caution against misapplication of this International Standard

The ratings presented in this International Standard apply only to NaCl and those environments that have been verified to be less than NaCl environments.

11.3 Keywords

Stress-corrosion cracking, stress-corrosion, stress-corrosion ratings, alternate immersion, salt spray, salt fog, salt water, metals, materials, materials selection

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[2] ECSS-Q-70-36A, Material Selection for Controlling Stress-Corrosion Cracking (Superseding ESA-PSS-01-736-1), January 20, 1998

[3] ECSS-Q-70-37A, Determination of the Susceptibility of Metals to Stress Corrosion Cracking, January 20, 1998

[4] MIL-HDBK-5, Metallic Materials and Elements for Aerospace Vehicle Structures

Figure 1 — Grain orientation in standard wrought forms

Figure 2 — Examples of tensile stresses in short transverse direction applied during assembly

Figure 3 — Examples of tensile stresses in short transverse direction resulting from assembly

Figure 4 — Typical residual stress distribution in 7075 aluminum alloy shapes

Table 1 — Class 1 ferrous alloys: Highly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
G10900 (example)	Carbon Steel, 1 000 Series	Below 1241 MPa (180 ksi) UTS
G43400, K24728, etc.	Low Alloy Steel (e.g., 4340, D6AC, 4130, etc.)	Below 1241 MPa (180 ksi) UTS
K08500	Music Wire	Cold Drawn
G10950	1095 Spring Steel	Quenched and Tempered
K31820	HY-80 Steel	Quenched and Tempered
K512555	HY-130 Steel	Quenched and Tempered
K512555	HY-140 Steel	Quenched and Tempered
Unknown	ASP 11	Aged
S20500 (example)	200 Series Stainless Steel (Unsensitized)	All
S31600 (example)	300 Series Stainless Steel (Unsensitized)[a]	All
S43000 (example)	400 Series Ferritic Stainless Steel (404, 430, 431, 444, etc.)	All
S24100	Nitronic 32, also known as 18-2 Mn	Annealed
S24000	Nitronic 33[b], also known as 18-3 Mn	Annealed
S21900	Nitronic 40, formerly 21-6-9[b]	Annealed
S21800	Nitronic 60	20% and 50% Cold Drawn
S66286	A286 Stainless Steel	All
S35000	AM 350 Stainless Steel	SCT 1 000[c] and Above
S35500	AM 355 Stainless Steel	SCT 1 000[c] and Above
S36200	AM 362 (Almar 362) Stainless Steel	3 Hours at 538 °C (1 000 °F) (H1000) and Above
N08020	Carpenter 20Cb3 Stainless Steel	All
S45000	Custom 450 Stainless Steel	H1000[d] and Above
S45500	Custom 455 Stainless Steel	H1000[d] and Above
S15500	15-5 PH Stainless Steel	H1000[d] and Above
S14800	PH 14-8 Mo Stainless Steel	CH900 and SRH950 and Above[e]
S15700	PH 15-7 Mo Stainless Steel	CH900[e]
S17700	17-7 PH Stainless Steel	CH900[e]
K91472	HP 9-4-20	All
N08904	904L Stainless Steel[f]	Annealed
N08367	AL-6XN[f]	Annealed
S31803	ES 2205[f]	Annealed
S32950	7 Mo Plus[f]	Annealed
N08026	20 Mo-6	Annealed
N08024	20 Mo-4	Annealed
Unknown	Maraging Steel MARVAL X12[g]	All

NOTE 1 Chemical composition of ferrous alloys listed in this table with unknown UNS numbers:

HY-130: 0,12 C, 0,6-0,9 Mn, 4,75-5,25 Ni, 0,4-0,7 Cr, 0,3-0,65 Mo, 0,02 Ti, 0,05-0,1 V, 0,15 Cu, Bal Fe

HY-140: 0-0,12 C, 0,6-0,9 Mn, 0,2-0,35 Si, 4,75-5,25 Ni, 0,4-0,7 Cr, 0,3-0,65 Mo, 0,05-0,1 V, 0,02 Ti, 0-0,15 Cu, Bal Fe

ASP 11: 0-0,04 C, 0-0,8 Si, 0-1,5 Mn, 0-0,3 Cu, 5,3-6,9 Ni, 23,5-25 Cr, 1,45-1,95 Mo, 0,3-0,5 Nb, 0,001-0,003 B, Bal Fe

904L: 0,02 C max, 2 Mn max, 1 Si max, 0,03 P max, 0,015 S max, 19-23 Cr, 23-28 Ni, 4-5 Mo, 1-2 Cu

NOTE 2 UNS = Unified Numbering System

[a] Including weldments of 304L, 316L, 321, and 347. The free machining grades (e.g., 303, 303SE) appear to be less resistant to SCC than other steels of this series.

[b] Including weldments.

[c] SCT 1000 = Subzero cooling and tempering at 538 °C (1 000 °F).

[d] H1000 = Hardened at 538 °C (1 000 °F).

[e] CH900 = Cold worked and aged at 482 °C (900 °F). SRH950 = Solution treated and tempered at 510 °C (950 °F).

[f] Evaluated with the Slow Strain Rate Technique.

[g] Evaluated with the constant load method.

Table 2 — Class 1 aluminum alloys: Highly resistant to stress-corrosion cracking in sodium chloride environments

Wrought			**Cast**		
UNS Number	**Alloy[a]**	**Temper[b]**	**UNS Number**	**Alloy**	**Temper**
A91090 (example)	1 000 Series	All	A03190, A13190	319,0, A319,0	As Cast
A92011	2011	T8	A03330, A13330	333,0, A333.0	As Cast
A92024	2024 Rod, Bar	T8	A03550, A33550	355,0, C355,0	T6
A92219	2219	T6, T8	A03560, A13560	356,0, A356,0	All
A92419	2419[c]	T8	A03570	357,0	All
A92618	2618	T6, T8[c]	A03580	358,0 (B358,0 or Tens-50)	All
A93002 (example)	3 000 Series	All	A03590	359,0	All
A95005 (example)	5 000 Series	All[d e]	A03800, A13800	380,0, A380,0	As Cast
A96061 (example)	6 000 Series	All	A05140	514,0 formerly 214	As Cast[e]
A97020	7020[c]	T6[f]	A05180	518,0 formerly 218	As Cast[e]
A97049	7049	T73	A05350	535,0 formerly Almag 35	As Cast[e]
A97050	7050	T73	A07100	710,0 formerly A712,0	As Cast
A97075	7075	T73	A07110	711,0 formerly C712,0	As Cast
A97149	7149	T73			
A97475	7475	T73			

NOTE Because metallurgical processing of aluminium alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this International Standard are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress-corrosion performance ratings of heat-treatable wrought aluminium alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.

[a] Including weldments of the weldable alloys, except otherwise specified.

[b] Including mechanically stress relieved (TX5X or TX5XX) tempers when applicable.

[c] Evaluated with the constant load method.

[d] High magnesium alloys 5456, 5053, and 5086 shall be used in controlled tempers (H111, H112, H116, H117, H323, H343) for resistance to stress-corrosion cracking and exfoliation.

[e] Alloys with magnesium content greater than 3,0 percent are not recommended for high temperature application, 66 °C (150 °F) and above.

[f] Excluding weldments.

Table 3 — Class 1 copper alloys: Highly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	CDAa Number	Condition (% Cold Rolled)b
C11000	110	37
C17000	170	AT[c], HT[d]
C17200	172	AT[c], HT[d]
C19400	194	37
C19500	195	90
C23000	230	40
C28000	280	0
C42200	422	37
C44300	443	10
C51000	510	37
C52100	521	37
C52400	524	0
C60600	606	0
C61900	619	40 (9% B phase)
C61900	619	40 (95% B phase)
C63200	632	0
C63800	638	0
C65500	655	0
C68800	688	40
C70400	704	0
C70600	706	50
C71000	710	0
C71500	715	0
C72500	725	40
C75200	752	50
C91700	917[e]	0
C93700	937[e]	0

a Copper Development Association.

b Maximum percent cold rolled for which stress-corrosion data is available.

c AT = Annealed and precipitation hardened.

d HT = Work hardened and precipitation hardened.

e Evaluated with the constant load method.

Table 4 — Class 1 nickel alloys: Highly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
N14052	Glass Seal 52 CR (51 Ni-49Fe)	All
K93601	Invar 36 (Including weldments)[a]	All
N10001	Hastelloy B	Solution Heat Treated
N10665	Hastelloy B2[a]	Annealed
N10002	Hastelloy C	All
N06455	Hastelloy C-4[a]	Annealed
N06022	Hastelloy C-22 (Including weldments)[a]	Annealed
N10276	Hastelloy C-276 (Including weldments)[a]	Annealed
N06030	Hastelloy G-30	Annealed
N06002	Hastelloy X	All
N08800	Incoloy 800	All
N08825	Incoloy 825	All
N09901	Incoloy 901	All
N19903	Incoloy 903	All
N06600	Inconel 600 (Including weldments)	Annealed
N06625	Inconel 625	Annealed
N07718	Inconel 718 (Including weldments)	All
N07750	Inconel X750	All
N05500	Monel K500 (Including weldments)	All
N09902	Ni-Span-C 902	All
N07041	Rene 41	All
Unknown	Unitemp 212	All
N07001	Waspaloy	All
Not assigned	NASA-23	All
Not assigned	Aerex 350	1627 MPa (236 ksi) UTS

NOTE Chemical composition of nickel alloys listed in this table with unknown UNS numbers:

Unitemp 212: 25 Ni, 16 Cr, 4,1 Ti, 0,57 Cb, 0,06 C, 0,1 B, 0,07 Zr, Bal Fe

NASA-23: 30 Ni, 14 Co, 9 Cr, 2,5 Nb, 2 Ti

Aerex 350: 43,8 Ni, 25,2 Co, 17,0 Cr, 4,02 Ta, 3,2 Mo, 2,27 Ti, 1,1 Cb, 0,021 C, 2,01 W, 1,16 Al, 0,16 Fe, 0,06 Si, 0,02 Mn, 0,001 S, 0,005 P

[a] Evaluated with the Slow Strain Rate Technique.

Table 5 — Class 1 miscellaneous alloys: Highly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
Unknown	Beryllium S-200C	Annealed
R30605	HS 25 (L-605)	All
R30188	HS-188[a]	All
R30035	MP-35-N	Cold Worked and Aged
R30159	MP-159	Cold Worked and Aged
R56320	Titanium 3Al-2,5V	All
R54520	Titanium 5Al-2,5Sn	All
R56400	Titanium 6Al-4V	All
R56410	Titanium 10V-2Fe-3Al	All
R58010	Titanium 13V-11Cr-3Al	All
Unknown	Titanium IMI 550	All
Unknown	Titanium IMI 685[b]	All
Unknown	Titanium IMI 829[b]	All
M15100	Magnesium M1A	All
M14141	Magnesium LA141	Stabilized
Unknown	Magnesium LAZ933	All

NOTE Chemical composition of various miscellaneous alloys listed in this table with unknown UNS numbers:
Beryllium S-200C: 98 Be, 2 BeO, 0,16 max Al, 0,15 max C, 0,18 max Fe, 0,08 max Mg, 0,08 max Si

a Including weldments.

b Evaluated with the constant load method.

Table 6 — Class 2 ferrous alloys: Moderately resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
G10900 (example)	Carbon Steel, 1 000 Series	1241 to 1379 MPa (180 to 200 ksi) UTS
G43400, K24728, etc.	Low Alloy Steel (4340, D6AC, 4130, etc.)	1241 to 1379 MPa (180 to 200 ksi) UTS
S21800	Nitronic 60[a]	Annealed
S42000 (example)	400 Series Martensitic Stainless Steel (e.g., 403, 410, 416, 431) except 440C	See footnote[b]
S35000	AM 350 Stainless Steel	Below SCT 1 000
S35500	AM 3355 Stainless Steel	Below SCT 1 000
S45000	Custom 450 Stainless Steel	Below H1000
S45500	Custom 455 Stainless Steel	Below H1000
S13800	PH 13-8 Mo Stainless Steel	All
S15500	15-5 PH Stainless Steel	Below H1000
S17400	17-4 PH Stainless Steel[c]	All
K91283	HP 9-4-30 (excluding weldments)	All

a This alloy may be considered borderline between class 1 and 2.

b Tempering between 371 °C and 593 °C (700 °F and 1 100 °F) shall be avoided because corrosion and stress-corrosion cracking resistance are lowered.

c For better stress-corrosion resistance tempering at 621 °C (1 150 °F) is recommended.

Table 7 — Class 2 magnesium alloys: Moderately resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
M11311	AZ31B	All
M16600	ZK60A	All
Unknown	ZW3 a	

[a] The condition for this alloy was not listed in the source.

Table 8 — Class 2 aluminum alloys: Moderately resistant to stress-corrosion cracking in sodium chloride environments

Wrought		
UNS Number	**Alloy**	**Condition**
A92024	2024 Rod, Bar, Extrusion	T6, T62
A92024	2024, Plate, Extrusion	T8
A92048	2048 Plate	T8
A92124	2124 Plate	T8
Not Assigned	2195 Al-Li	All
A94032	4032	T6
A95083	5083	All[a]
A95086	5086	All[a]
A95456	5456	All[a]
A97001	7001	T75, T76
A97010	7010[b]	T74 (T736[c])
A97049	7049	T76
A97050	7050	T74 (T736[c]), T76
A97075	7075	T76
A97175	7175	T74 (T736[c]), T76
A97178	7178	T76
A97475	7475	T76
Unknown	Russian Al-Li 1420[b]	Solution treated and aged
Unknown	Russian Al-Li 1421[b]	Solution treated and aged

NOTE 1 Mechanically stress relieved products (TX5X or TX5XX) shall be specified where possible.

NOTE 2 Sheet, unmachined extrusions, and unmachined plate are the most resistant forms.

NOTE 3 Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress-corrosion performance ratings of heat-treatable wrought aluminum alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.

NOTE 4 Chemical composition of 2195 Al-Li: 0,25-0,60 Ag, 3,7-4,30 Cu, 0-0,15 Fe, 0,8-1,2 Li, 0,25-0,80 Mg, 0-0,25 Mn, 0-0,12 Si, 0-0,10 Ti, 0-0,25 Zn, 0,08-0,16 Zr, Bal Al

[a] Except for the controlled tempers listed in Footnote c of Table 2, Aluminum Alloys. These alloys are not recommended for high temperature applications, 66 °C (150 °F) and above.

[b] Evaluated with the constant load method.

[c] Previous designation for the T74 temper.

Table 9 — Class 3 ferrous alloys: Lowly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
G10900 (example)	Carbon Steel, 1 000 Series	Above 1379 MPa (200 ksi) UTS
G43400, K24728, etc.	Low Alloy Steel (4340, D6AC, 4130, etc.)	Above 1379 MPa (200 ksi) UTS
T20811	H-11 Tool Steel	Above 1379 MPa (200 ksi) UTS
S44004	440C Stainless Steel	All
K92810	18 Ni Maraging Steela , 200 Grade	Aged at 482 °C (900 °F)
K92890	18 Ni Maraging Steel, 250 Grade	Aged at 482 °C (900 °F)
K92120	18 Ni Maraging Steel, 300 Grade	Aged at 482 °C (900 °F)
Unknown	18 Ni Maraging Steel, 350 Grade	Aged at 482 °C (900 °F)
S15700	PH 15-7 Mo Stainless Steel	All except CH900
S17700	17-7 PH Stainless Steel	All except CH900
H93100	AISI 9310	Carburized
K88165	M-50 NIL	Carburized
Unknown	CRB-7 Stainless Steel	All
K91283 (weldments)	HP 9-4-30 Weldments	All
K92580	AerMet 100	H875 and H900
S32550	Ferrallium 255b	Annealed
K94610	Kovar[c]	All

NOTE Chemical composition of ferrous alloys listed in this table with unknown UNS numbers:
18 Ni Maraging Steel, 350 Grade: per MIL-S-46850
CRB-7 Stainless Steel: 1,1 C, 0,40 Mn, 0,3 Si, 14 Cr, 2 Mo, 1 V, 0,25 Cb

[a] Carpenter NiMark

[b] Evaluated by using the Slow Strain Rate Technique.

[c] Evaluated with the constant load method.

Table 10 — Class 3 aluminum alloys: Lowly resistant to stress-corrosion cracking in sodium chloride environments

Wrought			Cast		
UNS Number	**Alloy**	**Condition**	**UNS Number**	**Alloy**	**Condition**
A92011	2011	T3, T4	A02950	295,0 (195)	T6
A92014	2014	All	A02960	296,0 formerly B295,0 or B195	T6
A92017	2017	All	A05200	520,0 (220)	T4
A92024	2024	T3, T4	A07070	707,0 (607, Ternalloy 7)	T6
A92024	2024 Forgings	T6, T62, T8	A07120	712,0 formerly D712,0, D612, or 40E	As Cast
A92024	2024 Plate	T62			
A92080	2080 Al-Li[a]	T8			
A92090	2090 Al-Li	T8E41			
A92219	2219	T3, T4			
A92618	2618[a]	T3, T4			
A97001	7001	T6			
A97005	7005	All			
A97020	7020[a]	Weldments			
A97039	7039	All			
A97075	7075	T6			
A97175	7175	T6			
A97079	7079	T6			
A97178	7178	T6			
A97475	7475	T6			
A98090	8090 Al-Li[a]	All			
Unknown	BS L93	T6			
Unknown	Russian Al-Li 1441[a]	All			
Unknown	Russian Al-Li 1460[a]	All			

NOTE 1 Mechnically stress relieved products (TX or TX5XX) shall be specified where possible.

NOTE 2 Sheet, unmachined extrusions, and unmachined plate are the least susceptible forms.

NOTE 3 Because metallurgical processing of aluminum alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress-corrosion perf ormance ratings of heat-treatable wrought aluminum alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.

[a] Evaluated with the constant load method.

Table 11 — Class 3 copper alloys: Lowly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	CDA[a] Number	Condition[b] % Cold Rolled
C26000	260	50
C35300	353	50
C44300	443	40
C67200	672	50, Annealed
C68700	687	10, 40
C76200	762	A, 25, 50
C76600	766	38
C77000	770	38, 50, Annealed
C78200	782	50

[a] Copper Development Association.

[b] Ratings based on listed conditions only.

Table 12 — Class 3 magnesium alloys: Lowly resistant to stress-corrosion cracking in sodium chloride environments

UNS Number	Alloy	Condition
M11610	AZ61A	All
M11800	AZ80A	All
Unknown	WE54	All
Unknown	ZCM711	All

Table 13 — Combined table for the relative resistance to stress-corrosion cracking of metallic materials in sodium chloride environments (combines Tables 1 through 12)

Material	UNS Numbera	Alloy	Condition	Class
Ferrous Alloys	G10900 (example)	Carbon Steel, 1 000 Series	Below 1 241 MPa (180 ksi) UTS	1
	G10900 (example)	Carbon Steel, 1 000 Series	1 241 to 1 379 MPa (180 to 200 ksi) UTS	2
	G10900 (example)	Carbon Steel, 1 000 Series	Above 1 379 MPa (200 ksi) UTS	3
	G43400, K24728, etc.	Low Alloy Steel (e.g., 4340, D6AC, 4130)	Below 1 241 MPa (180 ksi) UTS	1
	G43400, K24728, etc.	Low Alloy Steel (e.g., 4340, D6AC, 4130)	1 241 to 1 379 MPa (180 to 200 ksi) UTS	2
	G43400, K24728, etc.	Low Alloy Steel (e.g., 4340, D6AC, 4130)	Above 1 379 MPa (200 ksi) UTS	3
	K08500	Music Wire	Cold Drawn	1
	G10950	1 095 Spring Steel	Quenched and Tempered	1
	K31820	HY-80 Steel	Quenched and Tempered	1
	K512555	HY-130 Steel	Quenched and Tempered	1
	K512555	HY-140 Steel	Quenched and Tempered	1
	Unknown	ASP 11	Aged	1
	S20500 (example)	200 Series Stainless Steel (Unsensitized)	All	1
	S31600 (example)	300 Series Stainless Steel (Unsensitized)b h	All	1
	S43000 (example)	400 Series Ferritic Stainless Steel (e.g., 404, 430, 431, 444)	All	1
	S42000 (example)	400 Series Martensitic Stainless Steel, except 440C	See Footnotei	2
	S44004	440C Stainless Steel	All	3
	S24100	Nitronic 32, also known as 18-2 Mn	Annealed	1
	S24000	Nitronic 33[c], also known as 18-3 Mn	Annealed	1
	S21900	Nitronic 40 Formerly 21-6-9[c]	Annealed	1
	S21800	Nitronic 60	20% and 50% Cold Drawn	1
	S21800	Nitronic 60[d]	Annealed	2
	S66286	A286 Stainless Steel	All	1
	S35000	AM 350 Stainless Steel	SCT 1 000[e] and Above	1
	S35000	AM 350 Stainless Steel	Below SCT 1 000	2
	S35500	AM 355 Stainless Steel	SCT 1 000[e] and Above	1
	S35500	AM 355 Stainless Steel	Below SCT 1 000	2
	S36200	AM 362 (Almar 362) Stainless Steel	3 Hours at 538 °C (1 000 °F) (H1000 and Above)	1
	N08020	Carpenter 20Cb3 Stainless Steel	All	1
	S45000	Custom 450 Stainless Steel	H1000[f] and Above	1
	S45000	Custom 450 Stainless Steel	Below H1000	2
	S45500	Custom 455 Stainless Steel	H1000[f] and Above	1
	S45500	Custom 455 Stainless Steel	Below H1000	2
	S15500	15-5 PH Stainless Steel	H1000[f] and Above	1
	S15500	15-5 PH Stainless Steel	Below H1000	2
	S15700	PH 15-7 Mo Stainless Steel	CH900[g]	1
	S15700	PH 15-7 Mo Stainless	All except CH900	3

Material	UNS Numbera	Alloy	Condition	Class
	S17700	17-7 PH Stainless Steel	CH900[g]	1
	S17700	17-7 PH Stainless Steel	All except CH900	3
	K91472	HP 9-4-20	All	1
	N08904	904L Stainless Steel	Annealed	1
	N08367	AL-6XNh	Annealed	1
	S31803	ES 2205h	Annealed	1
	S32950	7 Mo Plush	Annealed	1
	N08026	20 Mo-6	Annealed	1
	N08024	20 Mo-4	Annealed	1
	S13800	PH 13-8 Mo Stainless Steel	All	2
	S14800	PH 14-8 Mo Stainless Steel	CH900 and SRH950 and Aboveg	1
	S17400	17-4 PH Stainless Steel[j]	All	2
	K91283	HP 9-4-30	All	2
	K91283	HP 9-4-30 Weldments	All	3
	T20811	H-11 Tool Steel	Above 1 379 MPa (200 ksi) UTS	3
	K92810	18 Ni Maraging Steel[k], 200 Grade	Aged at 482 °C (900 °F)	3
	K92890	18 Ni Maraging Steel, 250 Grade	Aged at 482 °C (900 °F)	3
	K93120	18 Ni Maraging Steel, 300 Grade	Aged at 482 °C (900 °F)	3
	Unknown	18 Ni Maraging Steel, 350 Grade	Aged at 482 °C (900 °F)	3
	Unknown	MARVAL X12 Maraging Steel	All	1
	H93100	AISI 9310	Carburized	3
	K88165	M-50 NIL	Carburized	3
	Unknown	CRB-7 Stainless Steel	All	3
	K92580	AerMet 100	H875 and H900	3
	S32550	Ferrallium 255[h]	Annealed	3
	K94610	Kovar	All	3
Aluminum Alloys – Wrought See Footnotes[l m n o]	A91090 (example)	1 000 Series (except for the Russian Al-Li alloys shown below)	All	1
	Unknown	1420 Russian Al-Li	Solution treated and aged	2
	Unknown	1421 Russian Al-Li	Solution treated and aged	2
	Unknown	1441 Russian Al-Li	All	3
	Unknown	1460 Russian Al-Li	All	3
	A92011	2011	T8	1
	A92011	2011	T3, T4	3
	A92014	2014	All	3
	A92017	2017	All	3
	A92024	2024 Rod, Bar	T8	1
	A92024	2024 Rod, Bar, Extrusion	T6, T62	2
	A92024	2024 Plate, Extrusions	T8	2
	A92024	2024 Plate	T62	3
	A92024	2024	T3, T4	3
	A92024	2024 Forgings	T6, T62, T8	3
	A92048	2048 Plate	T8	2
	Unknown	2080 Al-Li	T8	3
	A92090	2090 Al-Li	T8E41	3
	A92124	2124 Plate	T8	2
	Not Assigned	2195 Al-Li	All	2
	A92219	2219	T6, T8	1
	A92219	2219	T3, T4	3
	A92419	2419	T8	1
	A92618	2618	T6, T8	1
	A92618	2618	T3, T4	3
	A93002 (example)	3 000 Series	All	1
	A94032	4032	T6	2

Material	UNS Numbera	Alloy	Condition	Class
	A95005 (example)	5 000 Series	See Footnotesp q	1
	A95083	5083	See Footnotep	2
	A95086	5086	See Footnotep	2
	A95456	5456	See Footnotep	2
	A96061 (example)	6 000 Series	All	1
	A97001	7001	T75, T76	2
	A97001	7001	T6	3
	A97005	7005	All	3
	A97010	7010	T736	2
	A97020	7020	T6 (excluding weldments)	1
	A97020	7020 weldments	welded	3
	A97039	7039	All	3
	A97049	7049	T73	1
	A97049	7049	T76	2
	A97050	7050	T73	1
	A97050	7050	T74, T76	2
	A97075	7075	T73	1
	A97075	7075	T76	2
	A97075	7075	T6	3
	A97079	7079	T6	3
	A97149	7149	T73	1
	A97175	7175	T74, T76	2
	A97175	7175	T6	3
	A97178	7178	T76	2
	A97178	7178	T6	3
	A97475	7475	T73	1
	A97475	7475	T76	2
	A97475	7475	T6	3
	A98090	8090 Al-Li	All	3
	Unknown	BS L93	T6	3
Aluminum Alloys – Cast	A03190, A13190	319,0, A319,0	As Cast	1
	A03330, A13330	333,0, A333,0	As Cast	1
	A03550, A33550	355,0, C355,0	T6	1
	A03560, A13560	356,0, A356,0	All	1
	A03570	357,0	All	1
	A03580	358,0 (B358,0 or Tens-50)	All	1
	A03590	359,0	All	1
	A03800, A13800	380,0, A380,0	As Cast	1
	A05140	514,0 formerly 214	As Cast[q]	1
	A05180	518,0 formerly 218	As Cast[q]	1
	A05350	535,0 formerly Almag 35	As Cast[q]	1
	A07100	710,0 formerly A712,0	As Cast	1
	A07110	711,0 formerly C712,0	As Cast	1
	A02950	295,0 (195)	T6	3
	A02960	296,0 formerly B295,0 or	T6	3
	A05200	520,0 (220)	T4	3
	A07070	707,0 (607, Ternalloy 7)	T6	3
	A07120	712,0 formerly D712,0, D612, or 40E	As Cast	3
Copper Alloys[r s]	C11000	110	37	1
	C17000	170	AT[t], HT[u]	1
	C17200	172	AT[t], HT[u]	1
	C19400	194	37	1
	C19500	195	90	1
	C23000	230	40	1
	C28000	280	0	1
	C42200	422	37	1
	C44300	443	10	1
	C52100	521	37	1
	C52400	524	0	1
	C60600	606	0	1

Material	UNS Numbera	Alloy	Condition	Class
	C61900	619	40 (9% B phase)	1
	C61900	619	40 (95% B phase)	1
	C63200	632	0	1
	C63800	638	0	1
	C65500	655	0	1
	C68800	688	40	1
	C70400	704	0	1
	C70600	706	50	1
	C71000	710	0	1
	C71500	715	0	1
	C72500	725	40	1
	C75200	752	50	1
	C91700	917	0	1
	C93700	937	0	1
	C26000	260	50	3
	C35300	353	50	3
	C44300	443	40	3
	C67200	672	50, Annealed	3
	C68700	687	10, 40	3
	C76200	762	A, 25, 50	3
	C76600	766	38	3
	C77000	770	38, 50 Annealed	3
	C78200	782	50	3
Nickel Alloys	N14052	Glass Seal 52 CR (51 Ni-49Fe)	All	1
	K93601	Invar 36 (Including weldments)[h]	All	1
	N10001	Hastelloy B	Solution Heat Treated	1
	N10665	Hastelloy B2[h]	Annealed	1
	N10002	Hastelloy C	All	1
	N06455	Hastelloy C-4[h]	Annealed	1
	N06022	Hastelloy C-22 (Including weldments)[h]	Annealed	1
	N10276	Hastelloy C-276 (Including weldments)[h]	Annealed	1
	N06030	Hastelloy G-30[h]	Annealed	1
	N06002	Hastelloy X	All	1
	N08800	Incoloy 800	All	1
	N08825	Incoloy 825	All	1
	N09901	Incoloy 901	All	1
	N19903	Incoloy 903	All	1
	N06600	Incoloy 600 (Including weldments)	Annealed	1
	N06625	Inconel 625	Annealed	1
	N07718	Inconel 718 (Including weldments)	All	1
	N07750	Inconel X750	All	1
	N05500	Monel K500 (Including weldments)	All	1
	N09902	Ni-Span-C 902	All	1
	N07041	Rene 41	All	1
	Unknown	Unitemp 212	All	1
	N07001	Waspaloy	All	1
	Not Assigned	NASA-23	All	1
	Not Assigned	Aerex 350	1 627 MPa (236 ksi) UTS	1
Titanium Alloys	R56320	Titanium 3Al-2,5V	All	1
	R54520	Titanium 5Al-2,5Sn	All	1
	R56400	Titanium 6Al-4V	All	1
	R56410	Titanium 10V-2Fe-3Al	All	1
	R58010	Titanium 13V-11Cr-3Al	All	1
	Unknown	Titanium IMI 550	All	1
	Unknown	Titanium IMI 685	All	1
	Unknown	Titanium IMI 829	All	1

Material	UNS Numbera	Alloy	Condition	Class
Magnesium Alloys	M15100	Magnesium M1A	All	1
	M14141	Magnesium LA141	Stabilized	1
	Unknown	Magnesium LAZ933	All	1
	M11311	AZ31B	All	2
	M16600	ZK60A	All	2
	Unknown	ZW3	Condition not listed in source.	2
	M11610	AZ61A	All	3
	M11800	AZ80A	All	3
	Unknown	WE54	All	3
	Unknown	ZCM711	All	3
Miscellaneous Alloys	Unknown	Beryllium S-200C	Annealed	1
	R30605	HS 25 (L-605)	All	1
	R30188	HS 188[c]	All	1
	R30035	MP-35-N	Cold Worked and Aged	1
	R30159	MP-159	Cold Worked and Aged	1

NOTE 1 Chemical composition of alloys listed in this table with unknown UNS numbers:

HY-130: 0,12 C, 0,6-0,9 Mn, 4,75-5,25 Ni, 0,4-0,7 Cr, 0,3-0,65 Mo, 0,02 Ti, 0,05-0,10 V, 0,15 Cu, Bal Fe

HY-140: 0-0,12 C, 0,6-0,9 Mn, 0,2-0,35 Si, 4,75-5,25 Ni, 0,4-0,7 Cr, 0,3-0,65 Mo, 0,05-0,1 V, 0,02 Ti, 0-0,15 Cu, Bal Fe

ASP 11: 0-0,04 C, 0-0,8 Si, 0-1,5 Mn, 0-0,3 Cu, 5,3-6,9 Ni, 23,5-25 Cr, 1,45-1,95 Mo, 0,3-0,5 Nb, 0,001-0,003 B, Bal Fe

904L: 0,02 C max, 2 Mn max, 1 Si max, 0,03 P max, 0,015 S max, 19-23 Cr, 23-28 Ni, 4-5 Mo, 1-2 Cu

Unitemp 212: 25 Ni, 16 Cr, 4,1 Ti, 0,57 Cb, 0,06 C, 0,1 B, 0,07 Zr, Bal Fe

NASA-23: 30 Ni, 14 Co, 9 Cr, 2,5 Nb, 2 Ti

Beryllium S-200C: 98 Be, 2 BeO, 0,16 max Al, 0,15 max C, 0,18 max Fe, 0,08 max Mg, 0,08 max Si

Magnesium LA141: 1,2 Al, 0,15 Mn, 14 Li

Al-Li 2195: 0,25-0,60 Ag, 3,7-4,30 Cu, 0-0,15 Fe, 0,8-1,2 Li, 0,25-0,80 Mg, 0-0,25 Mn, 0-0,12 Si, 0-0,10 Ti, 0-0,25 Zn, 0,08-0,16 Zr, Bal Al

18 Ni Maraging Steel, 350 Grade: per Mil-S-46850

CRB-7 Stainless Steel: 1,1 C, 0,40 Mn, 0,3 Si, 14 Cr, 2 Mo, 1 V, 0,25 Cb

Aerex 350: 43,8 Ni, 25,2 Co, 17,0 Cr, 4,02 Ta, 3,2 Mo, 2,27 Ti, 1,1 Cb, 0,021 C, 2,01 W, 1,16 Al, 0,16 Fe, 0,06 Si, 0,02 Mn, 0,001 S, 0,005 P

NOTE 2 * Resistance to stress corrosion: Class 1 = high, Class 2 = moderate, Class 3 = low

Material	UNS Numbera	Alloy	Condition	Class

[a] UNS = Unified Numbering System.

[b] Including weldments of 304L, 316L, 321, and 347. It appears that the free machining grades (e.g., 303 and 303SE) are less resistant to SCC than other steels of this series.

[c] Including weldments.

[d] This alloy may be considered borderline between class 1 and class 2.

[e] SCT 1 000 = Subzero cooling and tempering at 538 °C (1 000 °F).

[f] H1000 = Hardened at 538 °C (1 000 °F).

[g] CH900 = Cold worked and aged at 482 °C (900 °F). SRH950 = Solution treated and tempered at 510 °C (950 °F).

[h] Evaluated with the Slow Strain Rate Technique.

[i] Tempering between 371 °C and 593 °C (700 °F and 1 100 °F) shall be avoided because corrosion and stress-corrosion cracking resistance are lowered.

[j] For better stress-corrosion resistance tempering at 621 °C (1 150°C) is recommended.

[k] Carpenter NiNark.

[l] Mechanically stress relieved products (TX5X or TX5XX) shall be specified where possible.

[m] Sheet, unmachined extrusions, and unmachined plate are the least susceptible forms.

[n] Including weldments of the weldable alloys.

[o] Because metallurgical processing of aluminium alloys usually results in a pronounced elongation of grains, the variation of susceptibility with grain orientation is more extensive than for other metals. The ratings presented in this document are for the direction of maximum susceptibility (short transverse direction for plate, transverse direction for bar, etc.). For specific stress-corrosion performance ratings of heat-treatable wrought aluminium alloys in various mill product forms and in other directions see MIL-HDBK-5, Table 3.1.2.3.1, or ASTM G64.

[p] High magnesium alloys 5456, 5083, and 5086 shall be used in controlled tempers (111, H112m H116, H117, H323, H343) for resistance to stress-corrosion cracking and exfoliation. These alloys are not recommended for high temperature applications, 66 °C (150 °F) and above.

[q] Alloys with magnesium content greater than 3,0 percent are not recommended for high temperature applications, 66 °C (150 °F) and above.

[r] Designation of the alloys is from the Copper Development Association.

[s] The maximum percent cold rolled for which stress corrosion data is available is presented under the condition column. Ratings based on listed conditions only.

[t] AT = Annealed and precipitation hardened.

[u] HT = Work hardened and precipitation hardened.

Summary

This International Standard was developed with the purpose of helping designers in the selection of metallic materials for stress-corrosion resistance so that failures would be prevented in service. Since stress corrosion involves the use of a susceptible material, a corrosive environment, a sustained tensile stress, and time, those factors shall be considered carefully by designers. The stress-corrosion testing method and criteria used for the classification of the alloys and weldments included in the tables of this standard are presented in ISO 16455-1.

This standard also contains general information on stress corrosion, an overview of the stress-corrosion performance of different engineering alloys, a description of the factors associated with stress corrosion, and the ways to reduce the possibilities for a stress-corrosion failure. The limitations of this standard are also presented. In addition, this document presents a procedure that shall be followed to request approval of materials that are susceptible to SCC, including an assessment of the potential for a stress-corrosion failure. This standard is based, for the most part, on NASA Marshall Space Flight Center (MSFC) standard MSFC-STD-3029, a stress corrosion document generated at NASA. It also considers other documents, such as documents previously published by ISO and the European Cooperation for Space Standardization (ECSS).

The mainline-stress corrosion testing procedure prescribed for alloys to be included in this standard employs the constant strain stressing method, the 0.318-cm (0.125-in) diameter round specimen configuration, the use of alternate immersion in 3,5 % NaCl per ISO 11130 as the corrosive environment, and a minimum 30-day exposure. Nearly all the alloys included in the tables of ISO 16455-2, were evaluated using this procedure. Other testing procedures are considered in this standard as supporting procedures. The use of a 3,5 % salt alternate immersion simulates the cycles to which many metallic materials used in aerospace and other industries are subjected to while in service in marine environments. Many of these materials, such as NASA Space Shuttle Solid Rocket Boosters, are subjected to wet-dry cycles in salt water. Though the ratings obtained using data generated with salt water are not applicable to all environments, it provides a good indication of how the alloys would perform in similar or less severe environments.

Alloys used for electrical wiring and other similar non-structural electrical or electronic applications are exempt from the requirements of this International Standard.

